10-Years of Intercomparisons of AIRS and ERA-Interim via PDFs

L. Larrabee Strow, Sergio De-Souza Machado,
Howard Motteler, and Andy Tangborn

Department of Physics, JCET
University of Maryland Baltimore County (UMBC)

AIRS Science Team Meeting
March 2014
Pasadena, CA

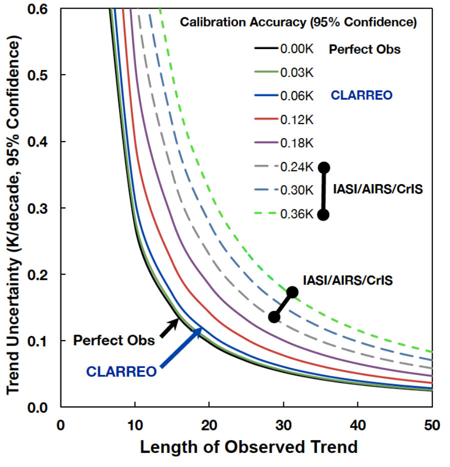
Overview

Can AIRS + CrIS contribute to climate level studies?

- Process data in radiance space as long as possible to ensure traceable accuracy
- Strive for "100%" sampling, or at least no scene-dependent sampling
- Instrument stability (AIRS)
- Radiometrically connect AIRS with CrIS
- Lower radiometric accuracy requirements by use of PDFs
- Do AIRS and CrIS contain the same information?
- In many cases still need to retrieve geophysical quantities: use zero as a-priori when possible
- Utilize climate quality data from other sources

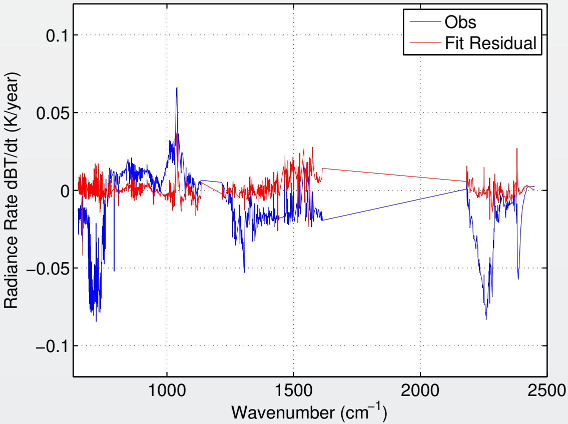
Emphasize well characterized measurements of trends over standard geophysical products that require additional information. Besides trending, what science can be done with this approach?

CLARREO LongWave Requirements



- Can we lower AIRS/CrIS effective calibration accuracy? Yes?
- Is the Trend Uncertainty (mean radiance change) the proper metric? Use PDF/quantile analysis to enhance detection.

AIRS Stability: Clear Subset Radiance Rate Fits

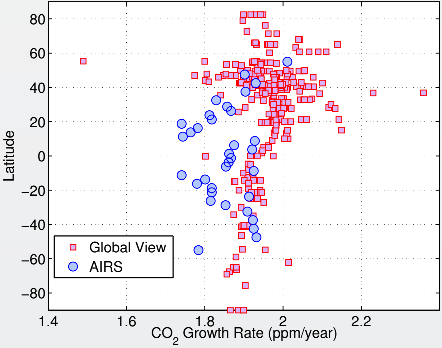


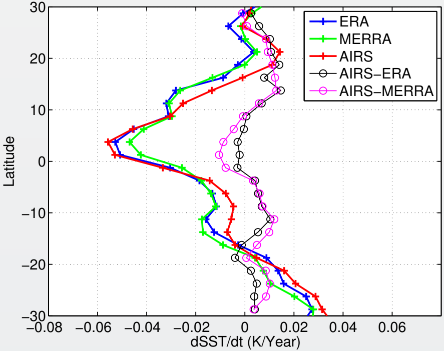
Is AIRS stable enough? 10-Year linear rates say yes.

Note: Not frequency corrected, no L1c

OEM Fit Results for Clear Ocean Subset

All a priori = 0, covariance = ~3X nominal variability



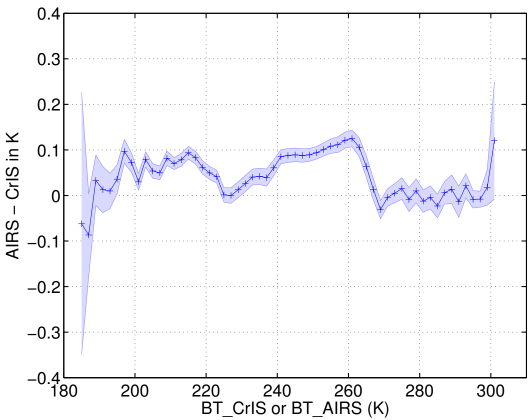


AIRS SST - SST CDR: +0.004 ± 0.006 K

AIRS CO_2 - In-Situ CO_2: -0.004 ± 0.004K

Connect AIRS to CrIS: SNO Comparisons at 900 cm^{-1}

Ensure agreement versus scene temperature

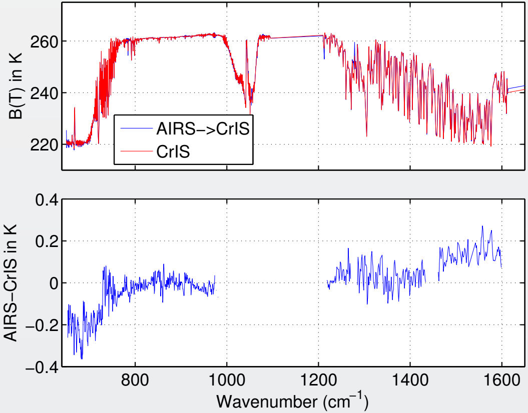


More work needed. See talk on Wed. on AIRS-CrIS SNO intercomparisons where AIRS is converted to CrIS ILS.

H. Motteler: AIRS -> CrIS ILS Conversion

Robust approach uses AIRS Measured ILS functions.

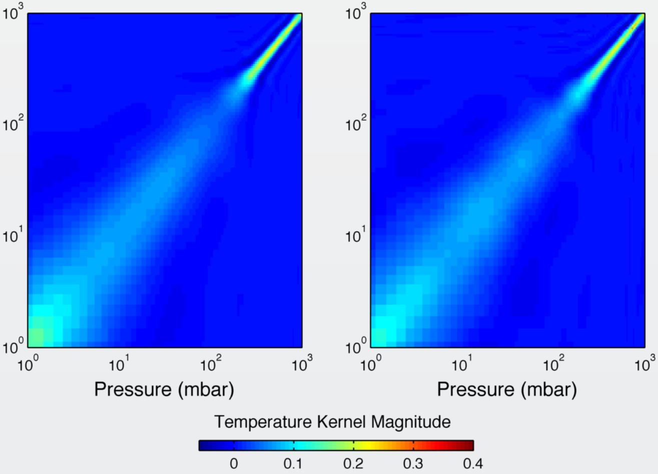
Convert AIRS ILS to CrIS for long-term radiance record.



This comparisons shows SNO intercomparisons for 1 day, Oct. 1, 2012. A key part of this work is JPL AIRS Project L1c product, removing effects of popping channels.

AIRS and CrIS Temperature Kernels, Tropical Profile

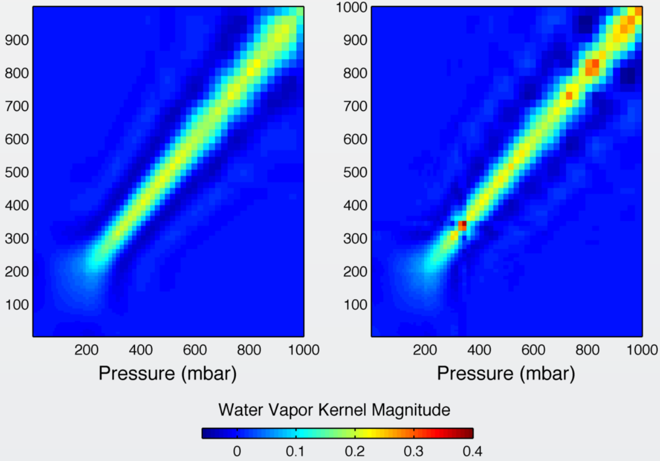
Left: AIRS, Right: CrIS



Assumes no RTA or instrument biases, errors. Unrealistic to do retrievals to CrIS noise level!

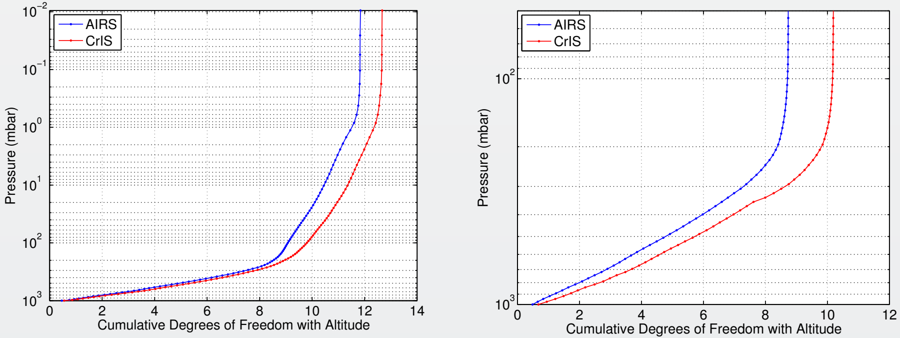
AIRS and CrIS Water Vapor Kernels, Tropical Profile

Left: AIRS, Right: CrIS



AIRS and CrIS: T(z) and H_2O (z) Degrees of Freedom

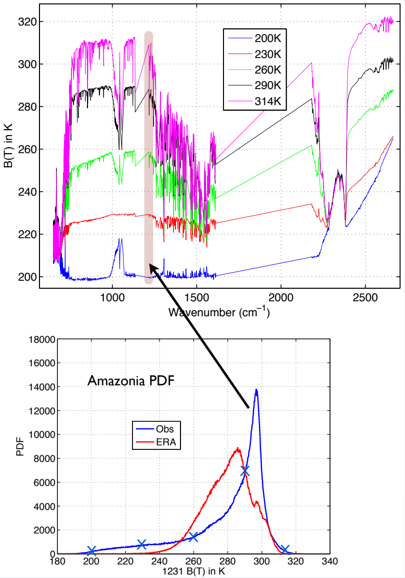
Left: T(z), Right: H_2O (z)



Again, cannot in practice take advantage of higher CrIS DOF's due to other errors.

PDF Measurement Approach

Do not average all-sky radiances.

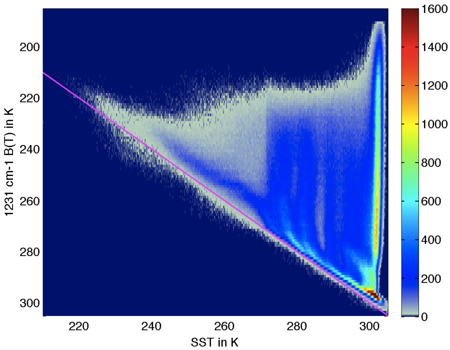


Retain more information: PDF rates, not Radiance Rates

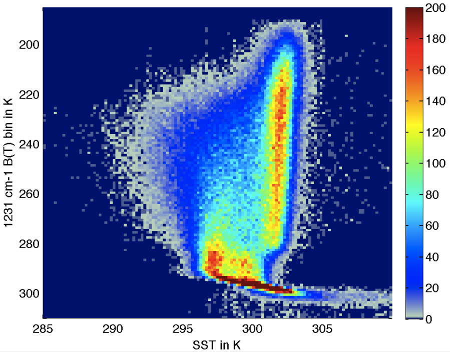
- Averaging clear with cloudy scenes destroys information
- Bin (create PDFs) versus variable related to cloudiness
- I used 1231 cm^{-1} channel B(T): clearest window channel
- Data Set: 10 years of AIRS, only FOVs on each side of nadir
- Bins of B(T) 1231 cm^{-1}, from 190:1:320K
- Mean BT spectra in each bin are stable versus time
- All the information is in the PDFs in each bin

PDF Examples

1231 cm^{-1} Global Ocean

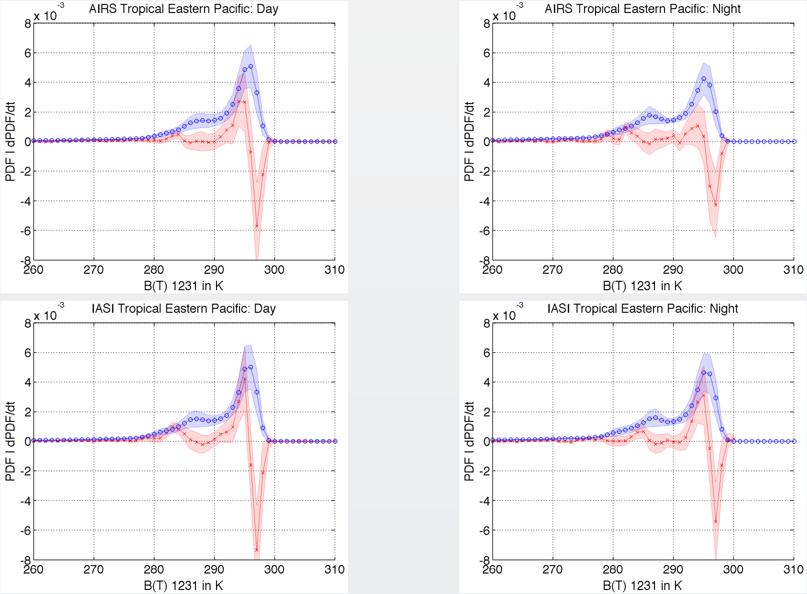


1231 cm^{-1} 15-25°Latitude

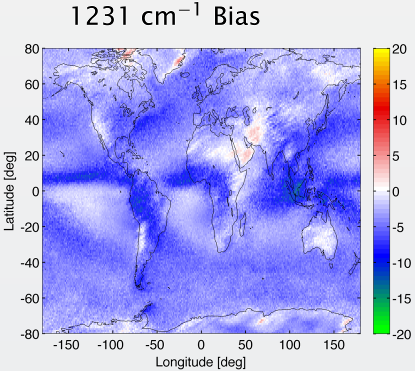


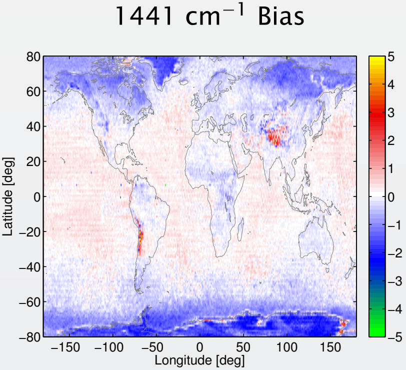
Diurnal Variability of PDF Rates (5-year rates)

PDFs divided by 25; Mean BT Rates (AIRS) -0.03K, -0.08K (IASI) 0.01K, 0.01K, all $2\sigma \sim 0.15$K



ERA+SARTA RTA Comparisons to Observations



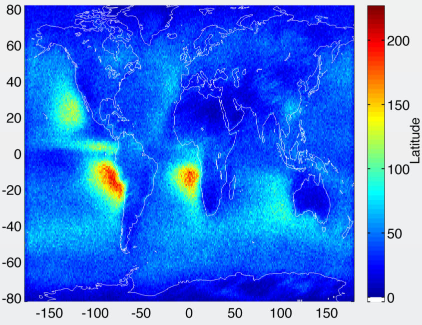


High cloud scenes removed for 1441 cm^{-1} bias analysis. Smoothness of 1231 cm^{-1} bias suggests that ECMWF cloud fields

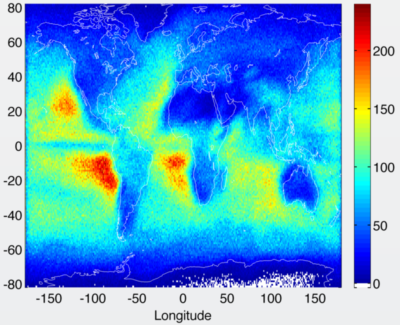
are quite good statistically and can possibly be used to generate a priori. Lower cloud forcing in ECMWF *may* be due to spatial resolution differences.

Marine Boundary Layer Cloud: Obs vs ERA

Obs: 6-12K Forcing



Calc: 2-7 Forcing



ERA grid size versus AIRS footprint may be part of these differences.

Quantile vs PDF Approach

- Previous approach: B(T) 1231 cm^{-1} is independent binning variable: find PDFs of B(T) 1231 since closely correlated with clouds.
- New approach: Make cumulative probability distribution independent variable: find mean value of B(T) 1231 in each "quantile" bin.
- Leads to easier interpetation

Quantiles (cumulative probability distribution): 0:dp:1. Sort B(T) in ascending order and fill bins.

Usually plot B(T) that goes with each dp bin, rather the cumulative probability.

SARTA Scattering RT Algorithm

- DISORT accurate (N streams) far too slow
- SARTA scattering based on: Chou, M.-D. and Lee, K.-T. and Tsay, S.-C. and Fu, Q., *Parameterization for Cloud Longwave Scattering for use in Atmospheric Models*, J.Clim, v12 (1999) PCLSAM
- Scattering OD is "effective" OD that depends on *Extinction, albedo, asymmetry*
  $\tau_{scatterer}(\nu, lay) = f(E_1(\tau, r), \omega(r), g(r))$
  where E_1 is extinction for 1 g/m2
- $\tau(\nu, lay) \rightarrow \tau_{atmgases}(\nu, lay) + \tau_{scatterer}(\nu, lay)$
- for two clouds with random overlap (based on NWP cloud cover field)
  $r(\nu) = c_1 r_1(\nu) + c_2 r_2(\nu) + c_{12} r_{12}(\nu) + c_{clr} r_{clr}(\nu)$

Scattering Parameters

Scattering databases as function of species (aerosol, water, cirrus), particle size (eg 0.3 μm to 10 μm), wavenumber

- Dust : (Mie) databases, different species, mostly use Volz(1873) refractive indices, but can bring in eg kaolinite, illinite etc (deff = 0.3 to 10 μm, typically 4 μm)
- Volcanic ash : (Mie) databases, basalt or andesite
- Water : (Mie) databases, refractive index from OPAC database (deff typically about 20 μm); lognormal particle size distributions
- Ice : Ice Aggregates or Hexagonol Plates, (deff 7 μm to 200 μm) (Anthony Baran, UKMO)
- Ice : New General Habit model scattering database (Ping Yang/Bryan Baum)

How "good" is PCLSAM

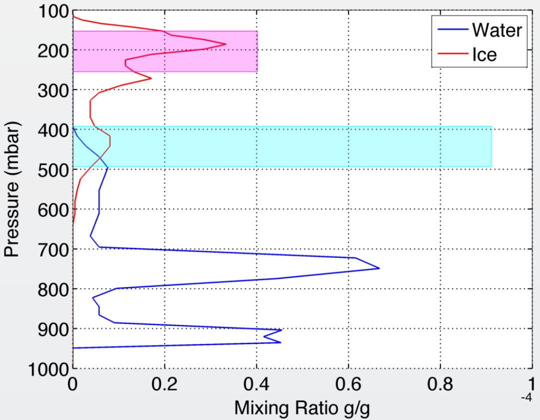
Compared it to PCRTM (based on DISORT)

- also uses Ping Yang/Bryan Baum ice scattering parameters
- (Mie) water cloud with fixed 20 um effective size
- 50 subcolumns Maximum Random Overlap wrapper

- SARTA TwoSlab with PCLSAM uses 4 streams, much faster than using 50 streams
- Can easily do (finite difference) Jacobians with SARTA TwoSlab
- Doing Cloud Jacobians with 100 layer SARTA code shows typically 2-4 degrees of freedom, so our parameterization of (cloud top, cloud amount) is "adequate" and captures cloud microphysics

SARTA TwoSlab - PCRTM MRO) $\simeq$ -0.25 $\pm$ 2 K

SARTA: 2-cloud layer RTA

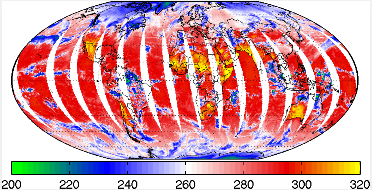


100-layer cloud RTA too slow for our purposes. Convert re-analysis cloud fields into two layers (water, ice). Top of cloud where optical depth is near unity. Results very similar to PCRTM (and SARTA 100-layer), far closer than differences to observations.

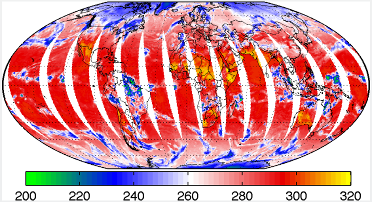
ERA -> SARTA versus 1231 cm^{-1} Obs

L2 all Q/A Very Good for Window Channel

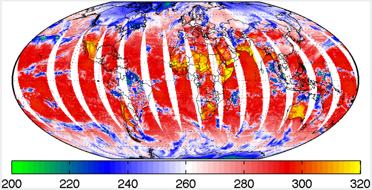
Observed B(T)



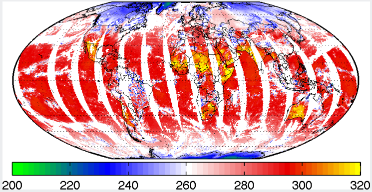
ERA B(T)



L2 Calc (all)



L2 Calc (good Q/A)



10-Year Linear Rates of 1231 cm^{-1} Channel

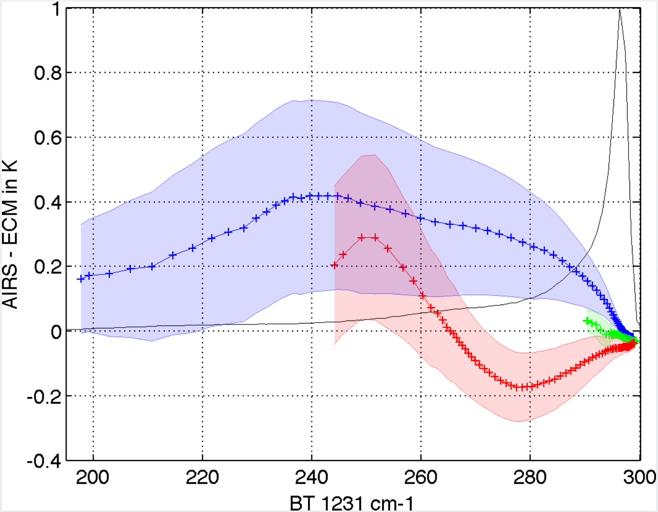
- Linear rate is a proxy for climate trends, uncertainties in mid- and lower-latitudes due to inter-annual variability.
- Highlights why CLARREO approach (all sky averages) will hide information.
- Uncertainties dominated by inter-annual variability.
- Allows examination of cloud vs clear behavior
- Can do similar analysis on anomalies

Procedures

- Subset data to some area (TWP, Arctic, etc.)
- Daily: Find average B(T)s on fixed cumulative probability grid (quantiles)
- Fit these time series (about 120 total) to remove seasonal component, and determine linear rate-of-change
- Examine *difference* between observed and simulated (from ERA) linear rates

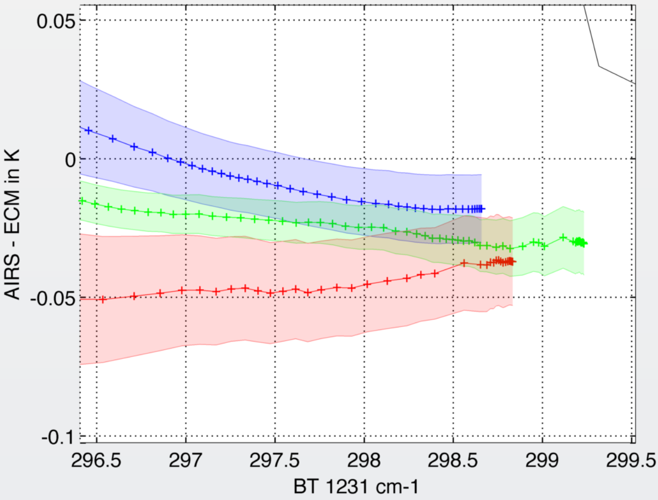
Tropical Western Pacific

10-Year Rate of 1231 cm^{-1} Channel; blue:obs, green:ECM clear calc, red:ECM cloud calc



Tropical Western Pacific: Hot BT Zoom

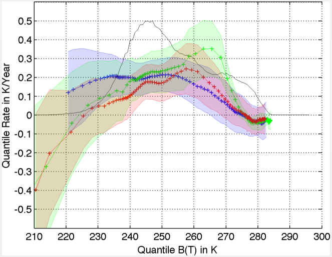
10-Year Rate of 1231 cm^{-1} Channel; blue:obs, green:ECM clear calc, red:ECM cloud calc



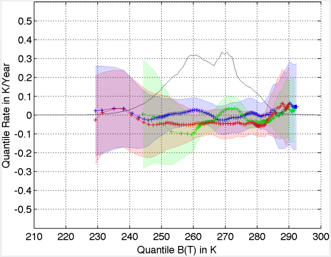
Arctic PDF 10-Year Rates

By Season; blue:obs, green:ECM clear, red:ECM cloudy

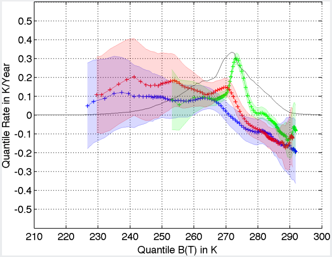
Winter



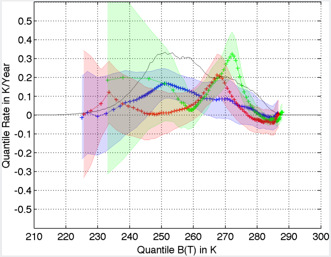
Spring



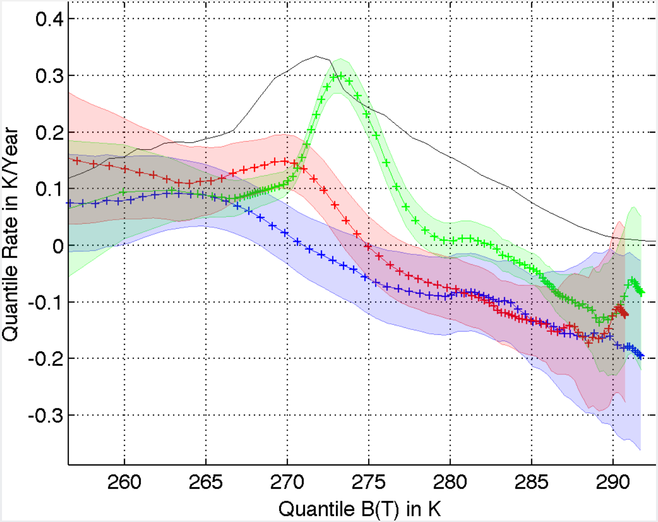
Summer



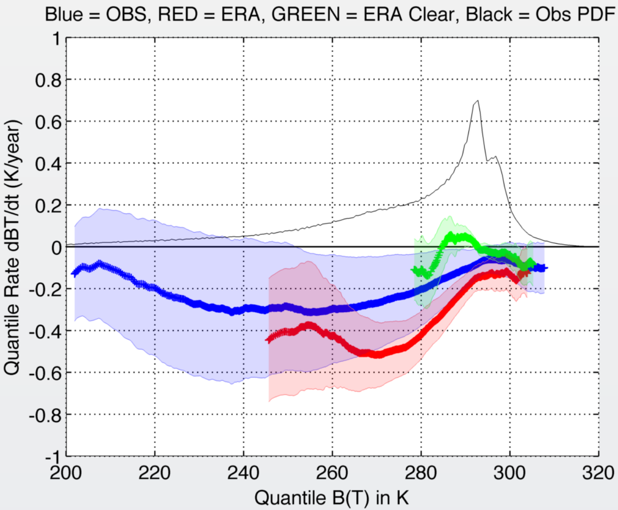
Fall



Zoom of Artic Summer



Amazonia



Mean rate: -0.09K ± 0.05K
Good agreement with ERA, lower cloud forcing

OEM Retrievals

March 11,2011; G039:DCC clouds near Indonesia, G137: MBL clouds off Namibia

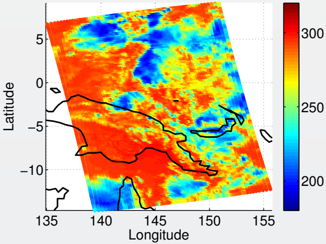
- Convert ECMWF clouds (67 layers) -> SARTA 2-layer clouds
- Compute simulated ECMWF radiances with SARTA
- Find ECMWF window radiance in granule closest to obs and use it for retrieval cloud; Fix cloud tops (hard part)
- Use parameterizations for ice, water cloud particle size
- A priori: ECMWF WV(z),T(z),O3(z),T_surf
- A priori WV(z) = 10%, column O3 and cloud amount = 10%, diagonal for now
- First fit for cloud ice/water only
- Second fit for WV(z) and column O3, keeping clouds fixed
- At most 10 iterations allowed, can update jacobians
- T(z) not fit, or emissivity
- In general, you can fit the data with 2 slab clouds!
- This is a 3-week effort!

Differences from PDF Approach

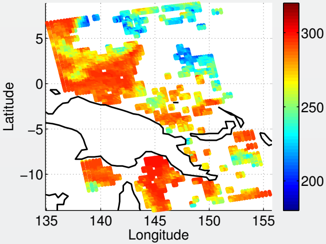
- This work: a priori is ECMWF, assuming 1K, 10% errors for T, water, clouds, etc. Observation error is noise, but forward model and instrument error can dominate.
- Trends using PDFs: a priori is zero, with covariances of maybe 3x estimated range of climate (works OK for clear scenes, earlier work). Probably fix dCO_2/dt. Observation error is inter-annual variability. Forward model bias largely cancels.

Granules Examined: 1231 cm^{-1} Images

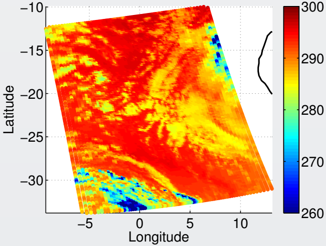
G039 Obs



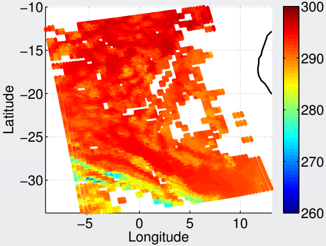
G137 ECM Calcs for Good QA



G137 Obs

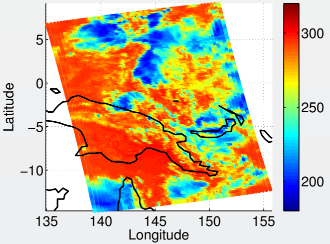


G137 ECM Calcs for Good QA

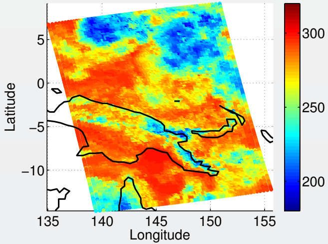


G039 Fits

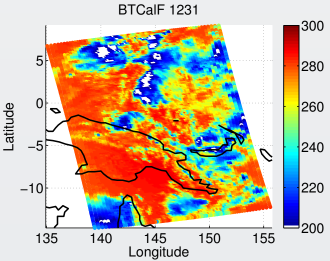
G039 Obs



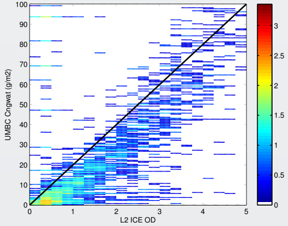
G039 ECM Calcs



G039 Calcs From Fit

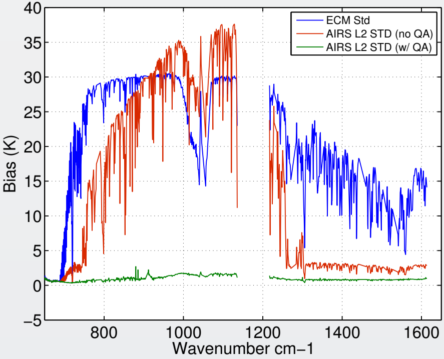


UMBC Ice Cloud vs L2 (Kahn et al.)

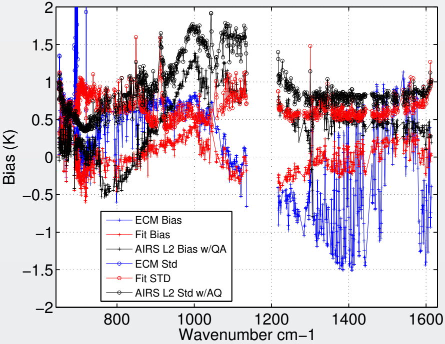


G039 Stats: Overview

Raw Std

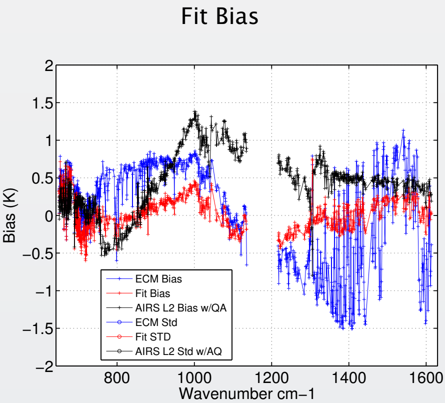


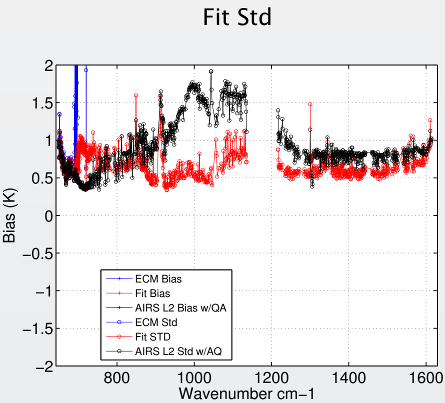
Fitting Stats



G039 Stats: Closure

L2 is 60% Sampling, UMBC Fit is ~100% !!

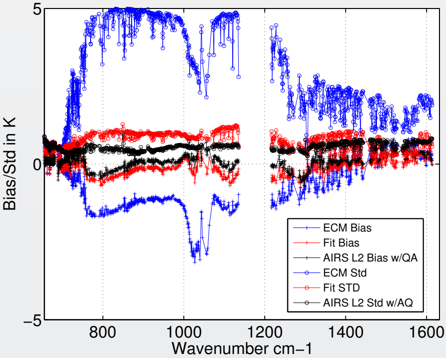




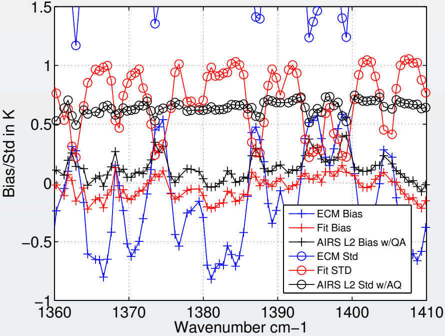
G137 Stats: Closure

L2 is ??% Sampling, UMBC Fit is ~100% !!

Overview



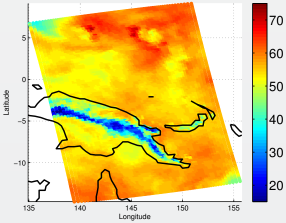
Water Band Zoom



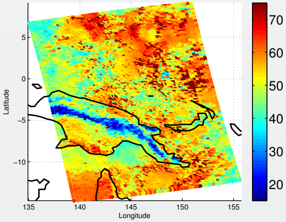
ECM boundary cloud placement incorrect for MBL clouds, causing window fitting errors.

G039 Water Retrievals

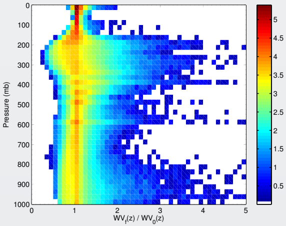
Column ECMWF



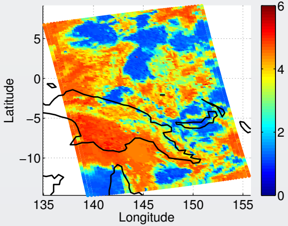
Column UMBC



Water(z) (UMBC/ECMWF)



Water Profile DOFS



Conclusions

- Single channel PDF analysis shows promise, good agreement with ERA re-analysis for clear scenes.
- Some differences (versus time) seen in tropical oceans, and in polar regions.
- Move to water vapor channels
- And then move to geophysical retrievals using full spectra
- Need average cloud parameters for Jacobians for PDF bins